Hydrological Application of Remote – Sensing and GIS for Handling of Excess Runoff

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***Abstract*— A GIS based hydrological analysis has been carried out to explore the possibility of diverting storm runoff generated from the upper catchment safely through a canal system constructed at the foothill to avoid flooding at downstream. The study area consisted of Kalapahar-Udyachal hills (5.38 km sq) in the Kahilipara- Odalbakra area, situated in the city of Guwahati, Assam. The Digital Elevation Model (DEM) of the study area was developed from the Survey of India(SOI) toposheet (1972) using Arcgis software. Watershed delineation and derivation of required topographic parameters for for calculating the peak discharge from different watersheds were done with the help of the generated DEM. Based on the hydrological analysis, means of safe diversion of runoff water from hillocks was found out and canal design of varying geometry capable of handling the peak discharge suggested.**

***Index terms* – GIS, Watershed, DEM, Runoff, Peak Discharge, Canal**

I. INTRODUCTION

Many hydrological models have been developed to simulate and to understand hydrologic processes. The hydrological models are used as a watershed management tool to provide a direction to utilize natural water resources effectively and beneficially. These models were concerned with predicting water quantities (e.g., runoff volumes and discharge) at a catchment or sub catchment outlet. Digital terrain models (DTMs) and remote sensing data have been used to characterize catchment (e.g., vegetation cover) and are now considered as crucial data input to the new generation of hydrological and water quality models. Different forms of digital terrain data such as digital elevations models (DEMs) and triangularly irregular networks (TIN) and contours) are used in different models to provide the spatial component of the analysis. The objective of the study is to suggest an economical way of diverting runoff water so as to prevent the problem of water logging at foothills.In order to do so peak discharge was calculated using rational formula. Watershed as such is the topography of any region and may be subdivided into several ecological units each of which drains to a common point. Each such unit is referred to as watershed. Strictly speaking, the higher land that separates each such unit is called a watershed, and the unit itself being termed as the catchment area. However, it has become fairly common now to speak of catchment area and watershed in identical terms. The size of a watershed may vary from a few hectares to thousands of square kilometers. Thus in short watershed is geo-hydrological unit draining to a common point.

II. BACKGROUND

One of the basic tasks in hydrological analysis is to delineate drainage basins and stream networks. The resulting stream networks can then be used in various applications, such as studies of stream flow hydraulics, prediction of flooding, and modeling of chemical transportation and deposition of pollutants in surface waterways. Traditionally, watershed delineation was mainly conducted by the manual delineation method. Although DEMs were introduced in the late 1950s, their application potential was not fully realized until the late 1980s when DEMs became widely available. With the advent of geographic information systems (GIS), DEMs have been used to delineate drainage networks and watershed boundaries,to calculate slope characteristics, to enhance distributed hydrologic models and to produce flow paths of surface runoff. The city of Guwahati is under constant threat of flash flood even from rainfall of short duration due to being surrounded by hills. Thus an effort has been made with the help of GIS tools and knowledge of hydrology to reach to conclusive and sustainable solution to tackle the problems of citizens of Guwahati. A hill termed as Udayachal- Kalapahar Hill in Survey of India Toposheet (1972) in the Kahilipara-Odalbakra area has been selected for this study By this study a tentative design of canal has been suggested to divert the excess water which might help the planners in finding sustainable solution to this problem.

A. Case Study in City of Guwahati

The Kalapahar and Udayachal hills of Guwahati city are taken up as the study area.

The following tools were provided for the case study:

- LISS IV MX Image Of Guwahati
- City(2009) Toposheet Of 1:50000 Scale (1972)

For the DEM development, watershed delineation and analysis ArcGIS version 9.1 was used.

III. METHODOLOGY

A. DEM Development

The ArcGIS tools were used in developing DEM (digital elevation model) of study area. DEMs are extremely valuable in understanding the properties of the terrain (e.g. slope, aspect, etc).

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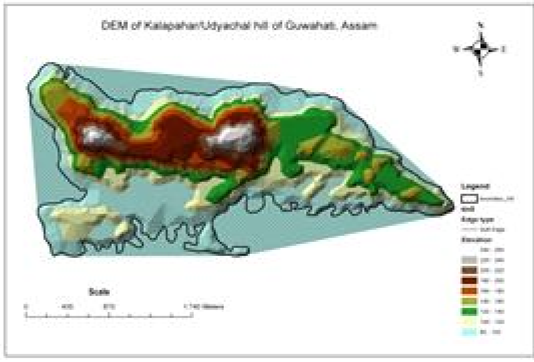

Fig 1– DEM of Study Area

B. Watershed Delineation

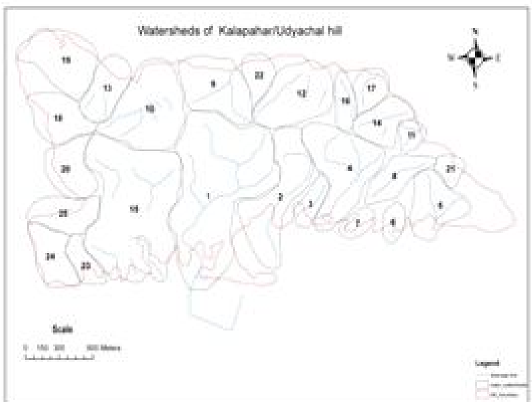

Fig 2– Watersheds of study area

The drainage lines were identified in this stage and watershed was delianiated with the knowledge of contour and drainage lines using slope map and DEM

C. Calculation of Intensity of Rainfall

The maximum intensity of rainfall from all 25 watersheds was found out using Maximum Intensity-Duration-Frequency relationship,

$$i = (K\, T^{x}) / (t_c + a)^{n} \qquad (1)$$

For calculation of intensity i:
Return period, T=15 for field diversion
K=7.206, x=0.1157, a=0.75, n=0.9401 for Guwahati
In formula above t_c, was calculated using Kiprich Equation (1940) ,

$$t_c = 0.01947\, L^{0.77}\, S^{-0.385} \qquad (2)$$

D. Calculation of Peak Discharge

With rainfall intensity available, the peak discharge for the individual watershed was found out using the Rational Equation,

$$Q = (CiA)/3.6. \qquad (3)$$

Q is Peak Discharge (m^3/s)
i= maximum intensity (mm/hr),
C is coefficient of runoff

E. Geometry of Channel Section

The peak discharge obtained for delineated watersheds are then utilized in calculation of channel section. The design calculation was done for most efficient trapezoidal section lined canal. In the lined canal with straight alignment, value of roughness coefficient, n=0.015. From Manning's equation,

$$Q = (A\, R^{2/3}\, S^{1/2}). \qquad (4)$$

Q is the peak discharge
A is area of section
R is hydraulic radius
S is channel slope
n is Manning constant
For trapezoidal section (half regular hexagon),

$$A = ”3\, y^2,\ R = y/2. \qquad (5)$$

(y is depth of flow)
Slope of the channel = 0.0004.
The above equation was then simplified in terms of y and Q,

$$y^{8/3} = Q \times 0.6873. \qquad (6)$$

IV. RESULT

For safe runoff diversion to natural streams, a total of six canals (FIGURE V) of varying geometry were found appropriate having a depth ranging from 1.511 m to 0.7 m. These are named Canal-0, Canal-1, Canal-2, Canal- 3, Canal-4 and Canal-5.The geometry of these canal sections was calculated using Manning's Equation. Economically most efficient trapezoidal section was selected for canal designing. Peak discharge (Table- II, Annexure), was calculated from Rational Formula and used in Manning's Equation for canal section geometry. Rainfall intensity was required in order to find out peak discharge for each watershed. This was calculated by finding out least time of concentration t_c from the Maximum Intensity-Duration-Frequency relationship(Table-II, Annexure).

A Geometry of Canal Section

The canals have been designed to handle the peak discharge. For economical efficiency, canals have been divided into sections depending on total peak discharge it has to handle at a particular point with depth of flow

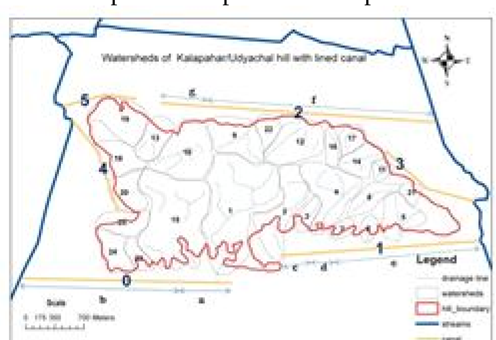

Fig 3 – Canal Plan for runoff diversion

increasing in steps. Result obtained thus was suitable for lined canal with straight alignment.
The calculated geometry of canal section (numbered) are given below for six canal sections.
The side slope for each canal is 1 in “3; width of each canal is two times depth
Canal- 0

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The canal "0" has been divided into two sections for handling the peak discharge
Section: a
Depth of canal = 1.134 m
Section: b
Depth of canal = 1.511 m
Canal-1
The canal has been divided into three parts for handling the peak discharge
Section: c
Depth of canal = 0.852 m
Section: d
Depth of canal = 1.075 m
Section: e
Depth of canal = 1.268 m
Canal-2
The canal has been divided into two parts for handling the peak discharge
Section: g
Depth of canal = 0.94 m
Section: f
Depth of canal = 1.321 m
Canal-3
Depth of canal = 0.7 m
Canal-4
Depth of canal = 0.912 m
Canal-5
Depth of canal = 0.71 m

The calculation for the depth of flow is done for the time taken for water from the farthest point on watershed to foothills. Considering the time of concentration as time taken for water to travel from farthest point of watershed to the exit at natural stream through a lined canal, the value of depth of flow of canal changes for the same peak discharge as the intensity of rainfall changes. Thus the new depth of flow was calculated by calculating first the intensity of rainfall for entire watershed for the six canal system individually using the Rational formula. Thereafter the time of concentration was calculated from Maximum Intensity – Frequency Duration relationship. From the calculated time of concentration the t_c as obtained in Annexure (Table I) was subtracted. The resulting time so obtained was the time taken for the water to travel from exit of watershed to exit of canal. With the length available and time obtained velocity was calculated. The velocity obtained was then used in Continuity Equation, for the peak discharge cross section area of canal was calculated individually. From the cross section area obtained the new and more accurate depth of flow was calculated. The result obtained were as mentioned.

The side slope for each canal is 1 in "3; width of each canal is two times depth.
Canal-0
Section: b
Depth of canal = 2.68 m
Canal-1
Section: e
Depth of canal = 2.56 m
Canal-2
Section: f
Depth of canal = 2.31 m
Canal-3
Depth of canal = 1.56 m
Canal-4
Depth of canal = 1.913 m
Canal-5
Depth of canal = 1.77 m

CONCLUSION

All the above results are meant for better handling of surface water for providing a sustainable solution to flash floods occurring low-lying areas nearby. The information obtained from such study can be implemented by planners and developers for sustainable development of any watershed. The work presented in this paper is of course not a comprehensive and does not include finer details for field implementation but still the basic idea can be implemented with intense micro analysis and relevant ground work in any development plans.

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ANNEXURE

TABLE I
TIME OF CONCENTRATION FOR WATERSHED

Sr. No.	L	H	S =H/L	T_c
1	1505	190	0.126	26.82966
2	1177	154	0.131	21.55329
3	487	53	0.108	12.67497
4	887	75	0.085	24.18174
5	577	82	0.142	11.682
6	340	30	0.088	11.25366
7	350	15	0.044	19.62576
8	734	65	0.088	20.34615
9	557	180	0.323	6.0357
10	807	157	0.194	11.89617
11	574	115	0.200	8.93673
12	782	143	0.183	12.14928
13	576	167	0.289	6.75609
14	578	84	0.145	11.52624
15	1360	162	0.119	25.93404
16	517	72	0.139	10.92267
17	430	73.5	0.170	8.11899
18	670	187	0.279	7.788
19	694	123	0.117	15.65388
20	580	172	0.296	6.65874
21	281	74	0.263	4.16658
22	476	148	0.311	5.51001
23	483	40	0.083	15.42024
24	661	41	0.062	24.59061
25	662	43	0.064	24.00651

TABLE II
PEAK DISCHARGE

Sr.No.	Area of Watershed	Peak Discharge
1	0.8788	2.03565232
2	0.34	0.78595452
3	0.0708	0.16400112
4	0.3527	0.81699428
5	0.1906	0.44150584
6	0.0507	0.11744148
7	0.0516	0.11952624
8	0.1276	0.29557264
9	0.2659	0.61593076
10	0.3787	0.87722068
11	0.0497	0.11512508
12	0.2794	0.64720216
13	0.1546	0.35811544
14	0.1382	0.32012648
15	0.7825	1.812583
16	0.0731	0.16932884
17	0.0858	0.19874712
18	0.1714	0.39703096
19	0.2592	0.60041088
20	0.1669	0.38660716
21	0.0499	0.11558836
22	0.0844	0.19550416
23	0.0771	0.17859444
24	0.1512	0.35023968
25	0.1539	0.35649396
TOTAL	5.384	12.4714976

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